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REPORT NO. DPS/TB5-0001/3

AUTOMOTIVE ENGINEERING LABORATORY

REPORT ON

TESTING ENGINES IN SIMULATED ATMOSPHERIC ENVIRONMENTS

Third Report on Ordnance Project No. TB5-0001

Engineering Laboratories Report No. 106

H. T. CLINE

APRIL 1960

ORDNANCE CORPS · U.S.A.

Aberdeen Proving Ground
Maryland

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TESTING ENGINES IN SIMULATED ATMOSPHERIC ENVIRONMENTS

Third Report on Ordnance Project No. TB5-0001

Engineering Laboratories Report No. 106

Dates of Test: November 1959 through February 1960

ABSTRACT

Tests were conducted to evaluate the capacity of the Aberdeen Proving Ground environmental chamber to simulate the wide range of environments in which automotive engines in military service may be required to operate.

A 345-cubic-inch, liquid-cooled, compression-ignition engine, together with an absorption dynamometer, was installed in the facility originally built for testing aircraft weapons. With the engine operating at maximum output, stabilized air temperature of -33°F was obtained in the intake manifold at about a 500-foot-altitude barometric pressure. Stabilized temperature as low as -25°F was obtained in the manifold at a simulated 10,000-foot altitude. At sea-level conditions, temperatures as low as -65°F can be obtained. Temperatures higher than +125°F can be obtained at all altitudes.

An envelope of basic and extreme atmospheric temperatures and pressures in which military engines will be required to operate has been established in this report. The chamber was capable of simulating all of the basic environmental conditions and about 85% of the extreme environmental conditions. Physically, the chamber will accommodate larger engines, although modifications to the refrigeration system will be required to obtain these low temperatures with the larger engines, particularly if they are air-cooled.

The environmental chamber provides a much needed facility for evaluating engine performance, engine and fuel compatibility, and cold-starting and warm-up characteristics of Ordnance engines.

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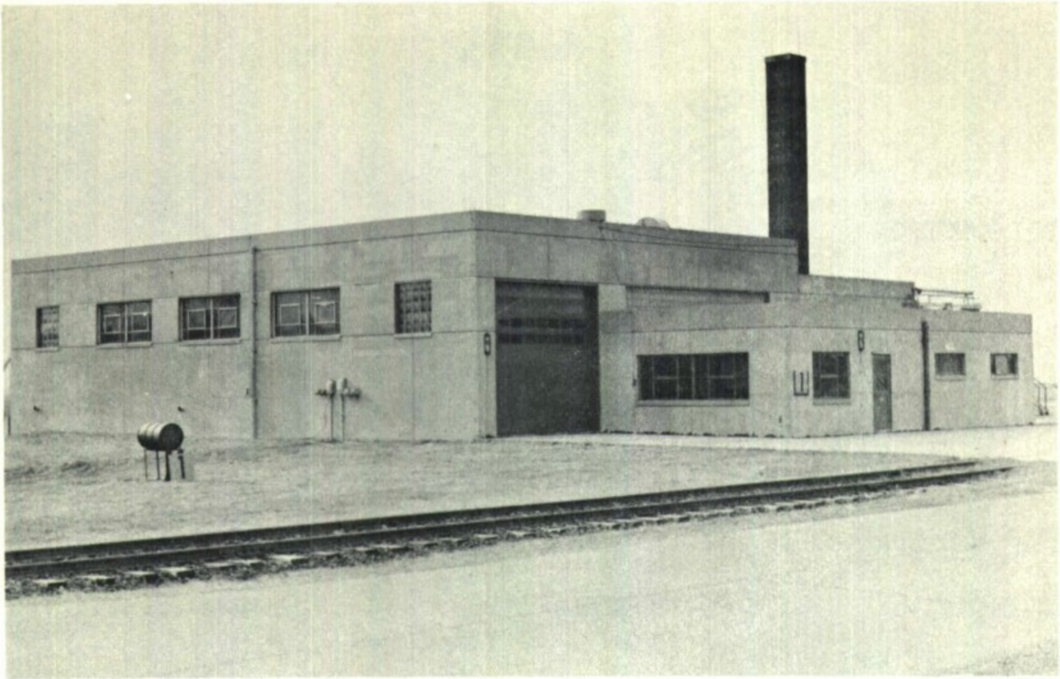


Figure 1: Building 384, Which Houses the Environmental Facility.

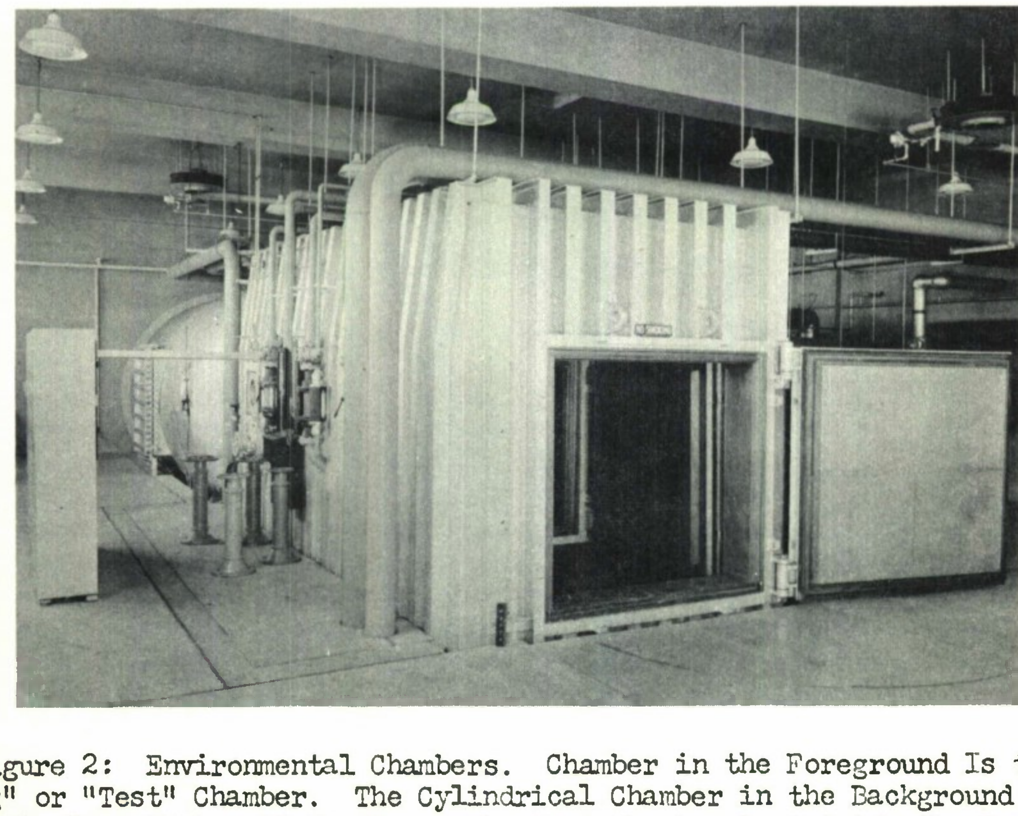


Figure 2: Environmental Chambers. Chamber in the Foreground Is the "Firing" or "Test" Chamber. The Cylindrical Chamber in the Background Is the "Concussion" or "Exhaust" Chamber. The Sand Chamber Is Outside the Building and Cannot be Seen.

1. INTRODUCTION

1.1 Objective

The tests described in this report were conducted to evaluate the capability of the Aberdeen Proving Ground environmental chamber to simulate the wide range of environments in which an automotive engine in military service may be required to operate.

1.2 Background

Much is yet to be learned of the effect of atmospheric pressures and temperatures on internal combustion engines for automotive application. Whether the engines be of the reciprocating, spark-, or compression-ignition type, or of the turbine type, changes in environment can affect the combustion process, the performance, the characteristics required of the fuel, and the fuel economy. Ordnance tests of current compression-ignition engines, for example, have shown that some engines will not tolerate some fuels or types of fuels when they are operated in extreme environments; but the reason for this is not clearly understood. To provide engines and fuels which are compatible under all conditions and yet conform to logistical requirements, it is necessary to understand combustion characteristics under all environments. Combustion and performance is best studied in the laboratory, but such studies require a facility which can simulate environments.

Such a facility exists at Aberdeen Proving Ground and, while it was built for testing aircraft weapons, it appears to be adaptable to the testing of reciprocating engines. This report covers the adaptation of the facility for testing automotive engines, the techniques employed, and the capability of the facility to simulate the environments in which an engine must be operated.

2. DESCRIPTION OF MATERIEL

2.1 The Environmental Facility

The environmental facility is housed in Building 384 (Figure 1), and can simulate a wide range of atmospheric pressures and temperatures. It consists of three interconnected chambers, a suction system, and two refrigeration systems. The fact that this facility was originally built for testing aircraft weapons accounts for the three chambers: the "firing" chamber, the "concussion" chamber and the "sand" chamber. For the testing of engines only two chambers, the "firing" and the "concussion," are used. For the purpose of this report, these two chambers will be redesignated as the "test" chamber and the "exhaust" chamber, respectively. These two chambers are shown on Figure 2, the vacuum pumps are shown on Figure 3, and the refrigeration plants are shown on Figure 4.

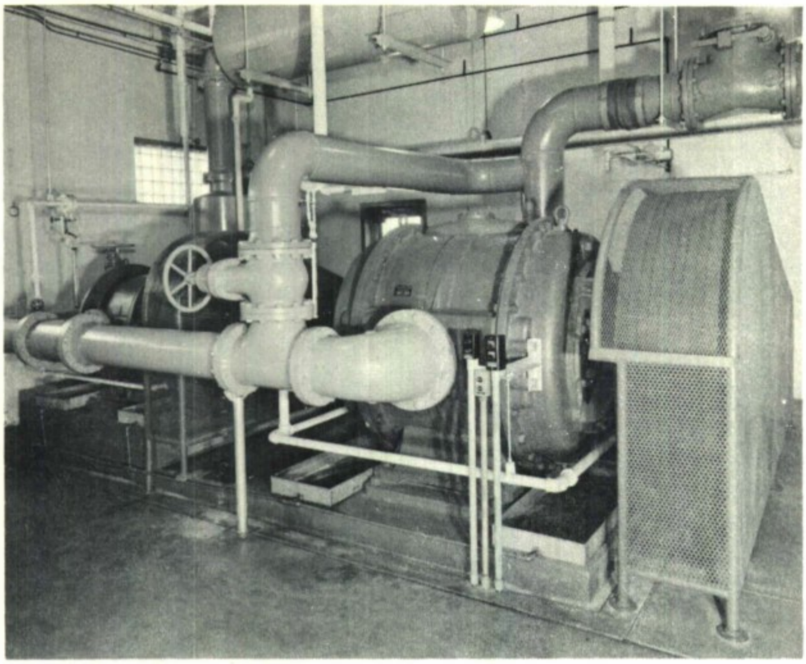


Figure 3: Vacuum Pumps. The Pump on the Left Is Rated at 1400 cfm While the Pump on the Right Is Capable of Evacuating 4000 cfm.

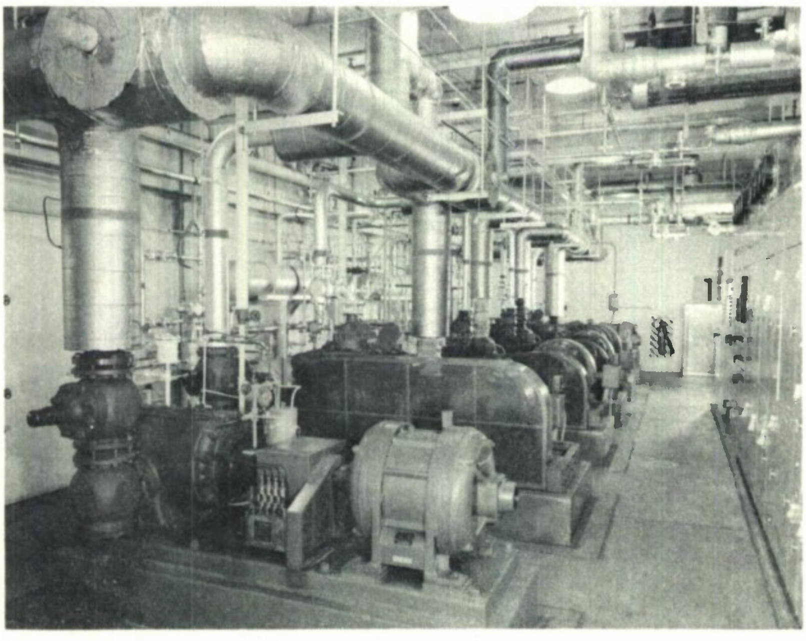


Figure 4: Two Three-Stage Compressor Systems Which Supply Refrigeration for the Environmental Chambers.

CLIMATIC RANGE

FIRING CHAMBER: +160°F TO −70°F AND AMBIENT PRESSURE TO EQUIVALENT OF 100,000 FT. IN ALTITUDE. NO HUMIDITY CONTROL IS AVAILABLE. AFTER PRE-COOLING (REQUIRES APPROX. 4½ HRS. FOR −70°F) TEMPERATURE AND PRESSURE CAN BE VARIED TO SIMULATE MAXIUM RATE OF CLIMB OF 5000 FT. PER MIN. STARTING AT +70°F AND SEA LEVEL PRESSURE TO 50,000 FT. ALTITUDE IN 10 MINUTES.

CONCUSSION CHAMBER: PROVIDES THE SAME CLIMATIC RANGE OF TEMPERATURE AND PRESSURE AS THE FIRING CHAMBER AND AT THE SAME RATES OF SPEED. THE CONCUSSION CHAMBER AND FIRING CHAMBERS CAN BE ISOLATED FROM EACH OTHER AT THE FIRING PORT AND EACH CHAMBER CAN THEN BE INDEPENDENTLY OPERATED.

FRESH AIR

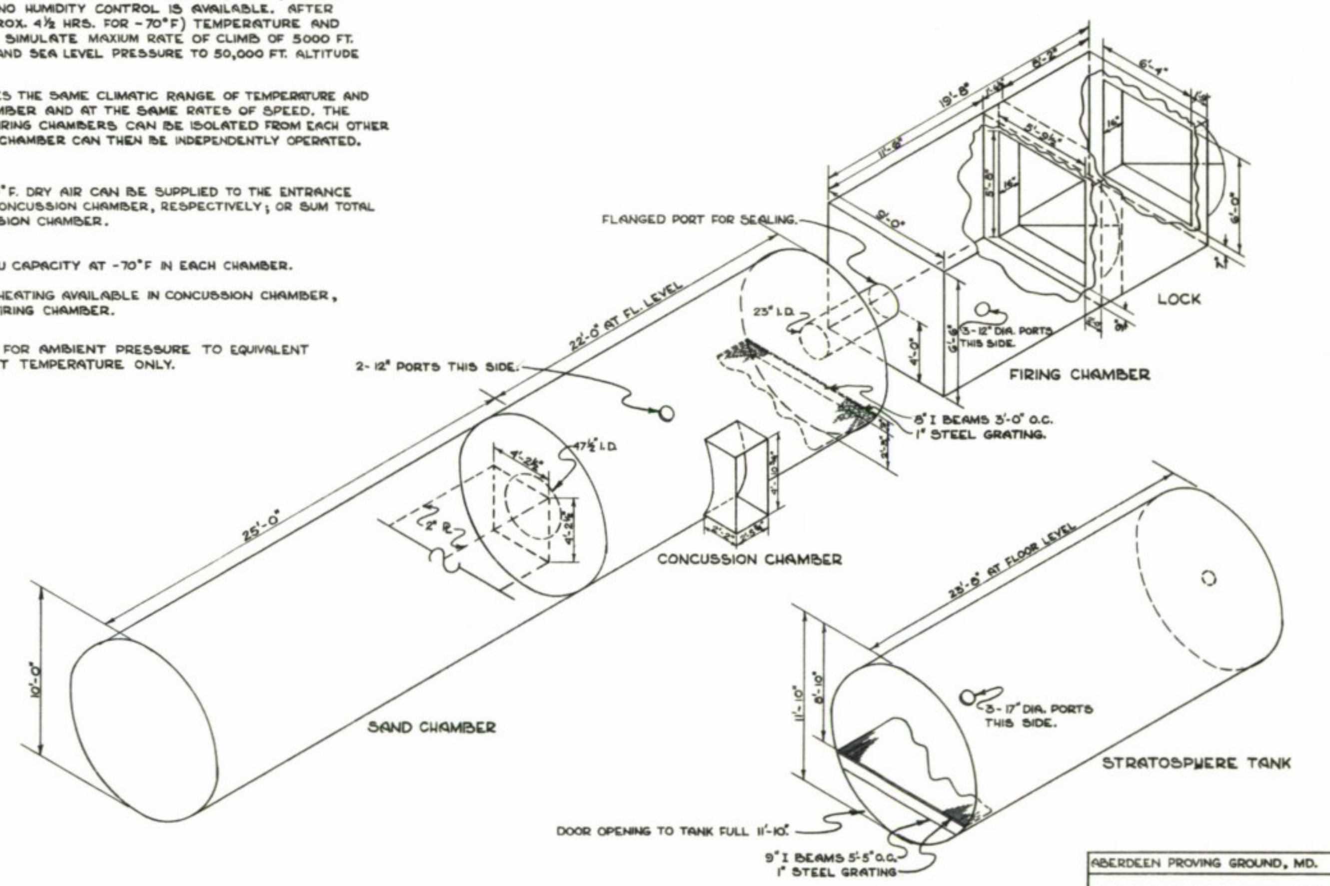
5 CFM, 20 CFM, 200 CFM OF 30°F. DRY AIR CAN BE SUPPLIED TO THE ENTRANCE LOCK, FIRING CHAMBER, AND CONCUSSION CHAMBER, RESPECTIVELY; OR SUM TOTAL TO EITHER FIRING OR CONCUSSION CHAMBER.

CAPACITY

COOLING: APPROX. 100,000 BTU CAPACITY AT −70°F IN EACH CHAMBER.

HEATING: 50 KW OF ELECTRIC HEATING AVAILABLE IN CONCUSSION CHAMBER, AND TWO (2) 15 KW UNITS IN FIRING CHAMBER.

STRATOSPHERE TANK: PROVIDES FOR AMBIENT PRESSURE TO EQUIVALENT 100,000 FT. IN ALTITUDE. AMBIENT TEMPERATURE ONLY.



ABERDEEN PROVING GROUND, MD.
STRATOSPHERIC FACILITY
DIMENSIONS INDICATE USABLE SPACE
WKD 2-11-57 FAC. ENG. BRANCH

FIGURE 5

Dimensions and basic characteristics of the altitude facility are given on Figure 5. This drawing shows that the test chamber has an air lock, but for these tests the door between the test chamber and the lock was kept open so that the total length of both was utilized as the test chamber. Both chambers (test and exhaust) are thermally insulated and are capable of simulating pressures encountered up to 100,000 feet above sea level and maintaining temperatures of minus 70° to plus 165°F. The amount of air entering or being evacuated from either or both chambers can be controlled in a variety of combinations.

Refrigeration for each of these two chambers is supplied by a three-stage compressor system using Freon 22 as the refrigerant. The cooling capacity of each system is rated at 100,000 Btu/hr. at minus 70°F. In the "test" chamber, cooling coils are located in the ceiling and a four-speed fan circulates the air over the coils and through the chamber. The rate of air circulation in the chamber can be controlled either by changing the fan speed, by positioning dampers located in the air stream before and after the coil, or by manipulating both. Cooling for the "exhaust" chamber is provided by coils located outside the chamber. For cooling, air is drawn from the chamber, passed over the coils and returned to the chamber. Again, dampers are used to aid in controlling the rate of air flow. Thirty kilowatts of heat are available in the test chamber and 50 kilowatts of heat are available in the "exhaust" chamber.

Three vacuum pumps are available to evacuate air from the chambers. Two of the pumps are shown on Figure 3. These pumps use water supplied at 60°F for their seal. They can draw a vacuum of about 20 in. H_g before the boiling point of water is approached. In terms of barometric pressure 20 in. H_g vacuum is equal to about 50,000 feet of altitude. The smaller of the two pumps is powered with a 75-hp motor and the other is powered with a 200-hp motor. Their rated capacity is 1400 and 4000 cfm. The pumps are intended to be used separately; the plumbing arrangement prohibits simultaneous operation of both pumps to obtain their combined capacity.

The third pump, which contains oil for its seal, is used to obtain vacuum in excess of 20 in. Hg but is not shown and will not be discussed here.

2.2 The Engine

An available six-cylinder, in-line, water-cooled, compression-ignition engine was selected for use in this evaluation. This naturally aspirated, four-stroke-cycle engine has a bore of 3.94 inches, a stroke of 5.12 inches and a compression ratio of 19.0 to 1. Its design uses the precombustion chamber and an in-line injection pump. The engine is rated at 105 hp at 2600 rpm and 239 ft-lb of torque at 1400 rpm.

3. ENVIRONMENTAL LIMITS FOR ENGINES

Environmental limits for engine operation must be established before the capability of the facility to simulate these limits can be evaluated. From a performance viewpoint, environmental parameters which have the greatest effect on the engine are barometric pressure and ambient temperature. Humidity also affects performance, but to a lesser degree. Certain environmental extremes are established by Army Regulation 705-15 (Reference 1). For example, basic operating limits are listed at -25°F and +115°F. Reference 1 also states that equipment must operate in temperatures of 115°F at 3000 feet of altitude and 90°F at 8500 feet of altitude. Extreme environmental limits are listed as -65°F and +125°F. With respect to humidity, the regulation states that equipment must operate in an atmosphere with a relative humidity of 100% and temperatures up to 85°F. Another requirement covered by Specification MIL-E-13929 (Reference 2) requires that engines operate satisfactorily in altitudes up to 12,000 feet.

Using these values, a chart of environmental envelopes of barometric pressure and ambient temperature in which an engine must operate has been constructed and is shown as Figure 6. The solid envelope represents the basic operational limits and the broken line represents the possible extreme limits. Little data are available for establishing the upper left portion of the envelope, but this extreme limit is believed to be realistic. This assumption is supported by Figure 7, where actual temperatures measured during military operation for Ordnance testing are plotted with respect to the envelope. No effort is made here to predict the probable operation within any portion of this envelope.

4. TECHNIQUES AND PROCEDURES

4.1 Adapting the Facility to Engine Testing

Without modifying the environmental facility in any way, the engine and a 400-horsepower, water-cooled, eddy-current dynamometer were coupled together and installed in the "test" chamber. Coolant (water) for both the engine and the dynamometer was piped through a chamber wall to a heat exchanger or directly to waste. Had it been intended to cold soak the engine for starting tests, an antifreeze solution would have been needed for both the engine and dynamometer, requiring closed cooling systems, circulating pumps and heater exchangers for each. Dynamometer and engine controls and instrumentation (except for dynamometer scales) were outside the test chamber and the leads were passed through pipe sleeves in the chamber (Fig. 8). The sleeves were sealed by filling them with paraffin wax. The dynamometer scales were read through one of the observation ports in the chamber wall.

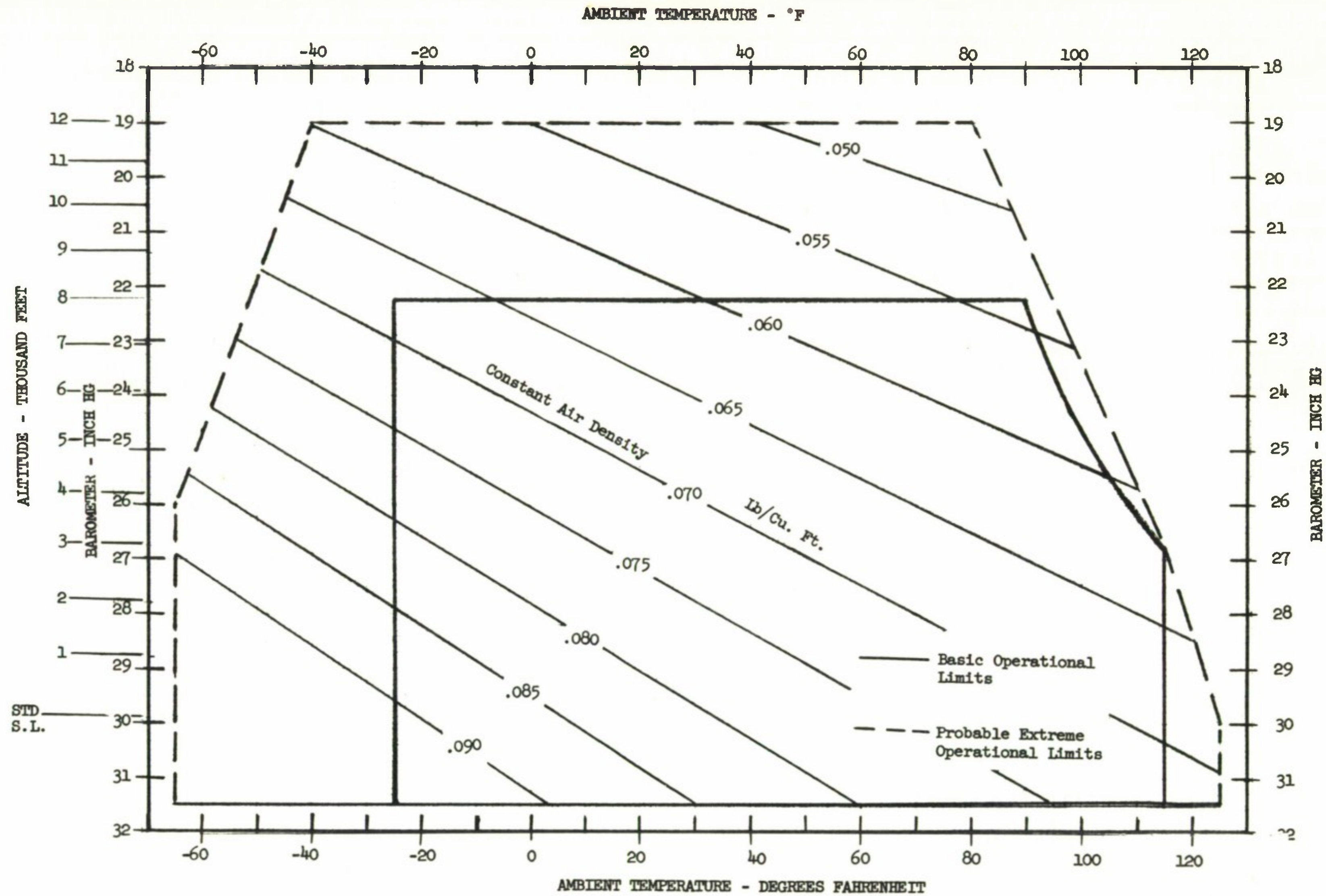


Figure 6: Environmental Limits for Automotive Engines.

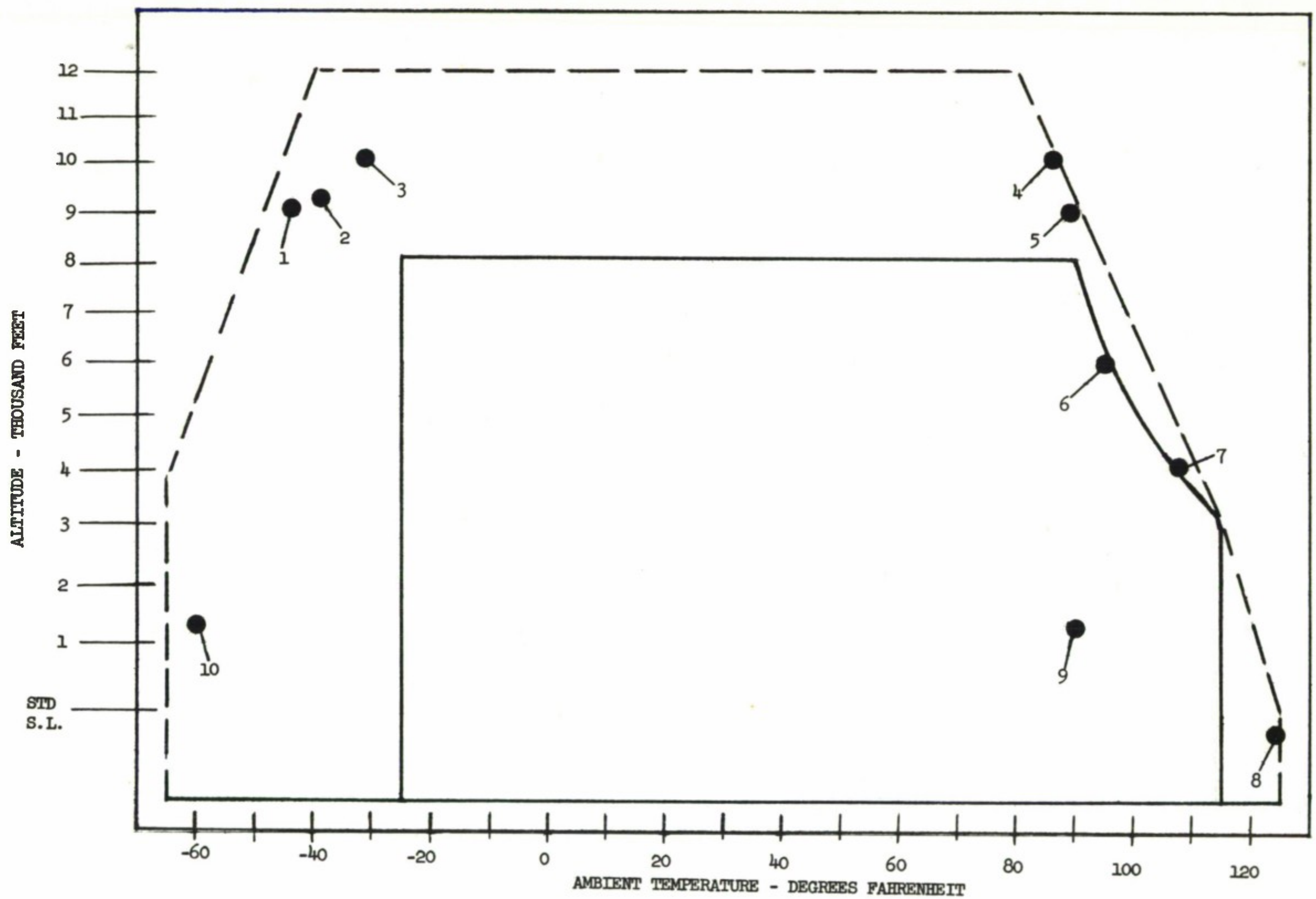


Figure 7: Temperatures Measured at Military Establishments and During Ordnance Tests Show That the Environmental Envelope Is Realistic.

Note	Location	Condition	Reference
1	Dillon, Colorado	Minimum Temp	C
2	Camp Hale, Colorado	Minimum Temp	C
3	Leadville, Colorado	Minimum Temp	C
4	Leadville, Colorado	Maximum Temp	C
5	Dillon, Colorado	Maximum Temp	C
6	Between Panamint Valley and Mahogany Flats, California	Measured during test	D
7	Daylight Pass, California	Measured during test	E
8	Death Valley, California	Measured during test	E
9	Fort Greely, Alaska	Maximum Temp	F
10	Fort Greely, Alaska	Minimum Temp	F

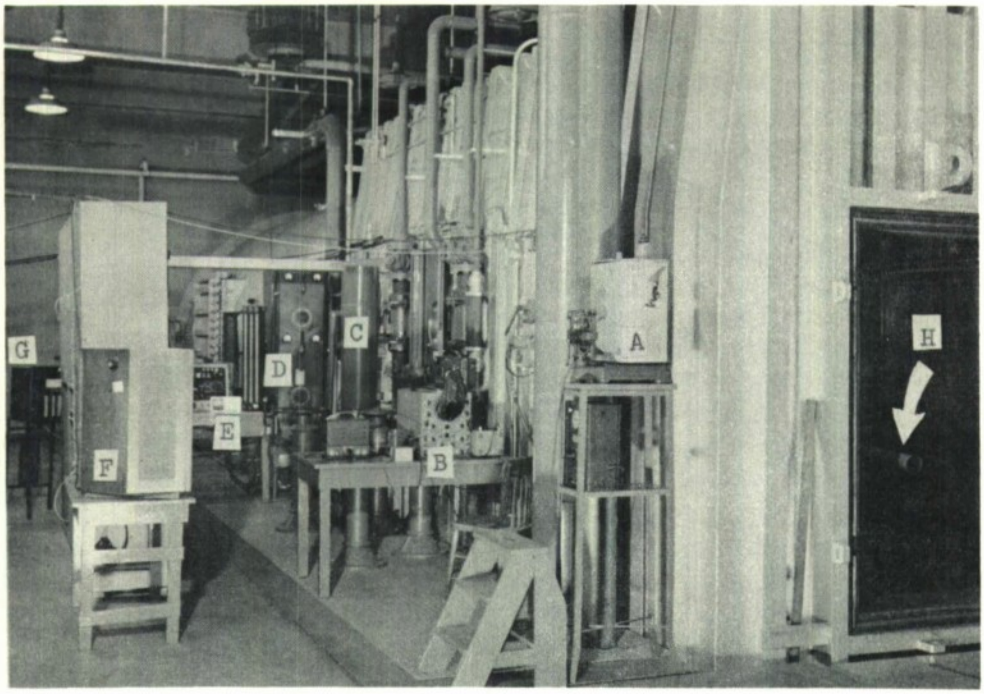


Figure 8: Instrumentation for Engine and Dynamometer Installed Along the Outside of the Environmental Chamber.

A - Fuel Weighing System.
B - Combustion Pressure Instrumentation.
C - Heat Exchanger for the Engine.
D - Dynamometer Control Panel.
E - Engine Controls.
F - Audio System for Monitoring Engine Noise.
G - Temperature Indicating Instrumentation.
H - Nozzle for Measuring Air Flow.

The engine exhaust gases were conducted to the "exhaust" chamber by a thermally insulated pipe attached to the engine exhaust manifold as shown in Fig. 9.

For these tests, all air (about 1400 cfm) to the chamber was drawn through the "test" chamber and, for the minimum temperatures, the fans which circulate the air over the cooling coils were run on their fourth speed to circulate air at the greatest rate. Fourth speed on these fans is intended for use in the less dense air encountered above an altitude of 50,000 feet, and because this speed was used at sea level and 10,000 feet of altitude the motor was overloaded and operation was temporarily interrupted by the thermal-protection breakers on the motor.

Because this was an exploratory test, the number of remotely activated devices on the engine was purposely limited to those essential for the operation. For this series of tests, the engine was started and stopped and adjustments were made to injection timing by personnel within the chamber while the room was at sea-level pressure. After the engine was started, the door to the chamber was closed and the required temperatures and pressures were maintained.

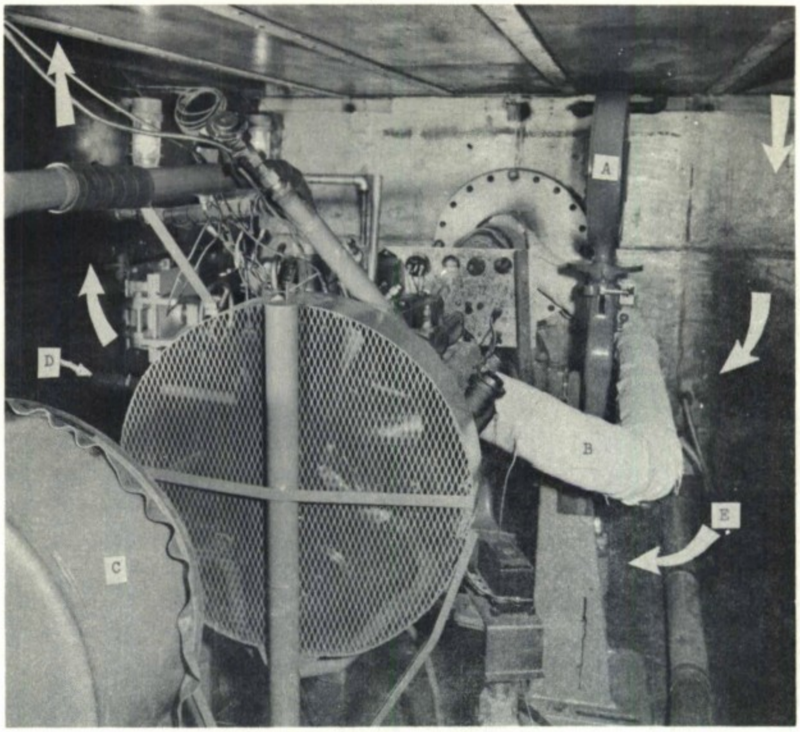


Figure 9: The Engine and Dynamometer Installed in the Test Chamber.

A - Dynamometer Scales.
B - Insulated Exhaust Line.
C - Plenum Chamber for Air-Flow Nozzles.
D - Coolant Lines Piped Through the Chamber Wall.
E - Arrows Indicate Path of Circulated Cold Air.

4.2 Fuel and Air Consumption

The amount of fuel and air consumed by the engine was measured during operation in the various environments. Fuel flow was measured by determining the time required to consume a known weight of fuel. The fuel-weighing scale was located outside the chamber. Air flow was measured using calibrated nozzles. The nozzles were installed in a plenum chamber inside the test chamber and the pressure sensing "U" tubes were located outside the test chamber. As with all manometers and "U" tubes used in these tests, the atmospheric pressure sides of the instruments were vented to the test chamber.

4.3 Combustion Pressure Measurements

The pressures generated in the No. 1 cylinder of the engine were sensed and recorded during operation in various environments. Pressures were sensed by a miniature crystal transducer adapted to the glow-plug hole of the cylinder. The transducer output, together with an indication of injection nozzle opening, was displayed on a two-beam oscilloscope and recorded by a 35-mm strip camera.

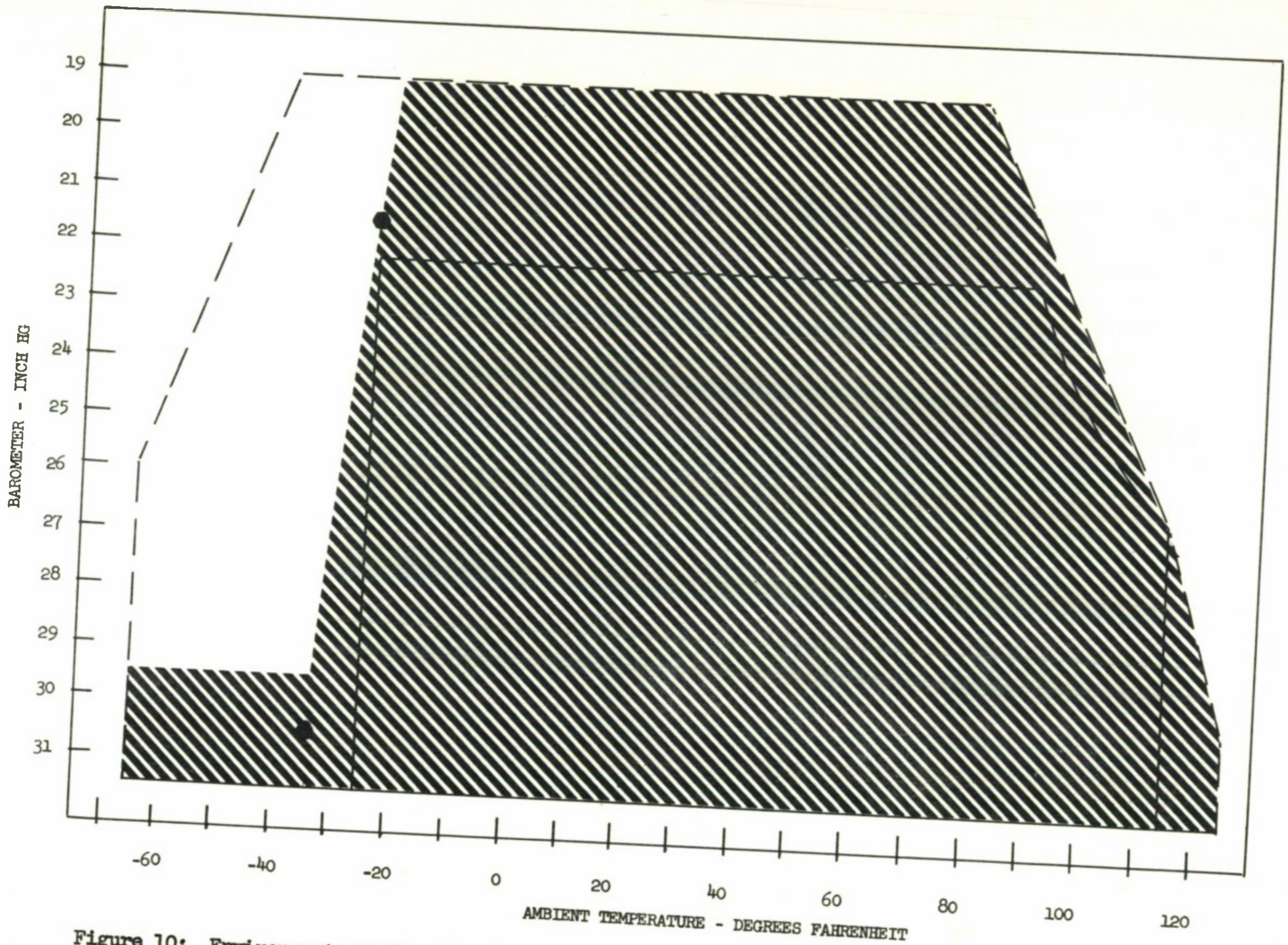


Figure 10: Environments Within the Shaded Area Can Be Simulated in the Chamber With the 345-Cubic-Inch Engine Operating at Maximum Power.

5. RESULTS

The 345-cubic-inch, compression-ignition engine was successfully operated over a wide range of environments. The various aspects of the test are discussed categorically.

5.1 Simulated Environments

A minimum stabilized temperature of minus 33°F was obtained in the intake manifold at sea level while the engine operated at maximum output. A minimum stabilized temperature of minus 25°F was obtained at a simulated 10,000-foot elevation under the same operating conditions. Air temperatures of 115°F were obtained in the test chamber and in the intake manifold at both sea level and simulated 10,000-foot elevation, and these were not maximum temperatures because the electric heaters were not used. When these results are plotted on the previously established environmental envelope as is done on Figure 10, it becomes evident that the chamber simulates all conditions within the basic operational envelope and about 85% of those within the extreme environmental envelope. An example of the effect of environment on the performance of the engine is shown on Figure 11, where the engine was operated at full rack at a constant speed and barometric pressure. Engine coolant was maintained at 170°F and the chamber temperature was varied between 55°F and minus 35°F. Except for the coolant, engine temperatures were allowed to vary with room temperatures; however, fuel and lubricant temperatures can be controlled to simulate field operation.

5.2 Rate of Change of Environment

The environment in the chamber can be changed quickly even when the engine is operating at maximum output. Within the temperature range 100° to 0°F, temperature can be dropped at a rate of at least 10°F/minute. Rate of change in ambient pressures was purposely limited to about 5000 feet/minute. The maximum rate of change was not determined. Examples of temperature and pressure change are shown on Figures 12 and 13.

5.3 Temperature and Pressure Control

Both temperatures and pressures in the environmental chamber are controlled manually. The degree with which temperature can be controlled depends on the proficiency of the operator. During those portions of the test where data were being recorded, manifold temperatures were held within ± 2°F of the required temperature.

Pressure in the room was maintained within ± 1 millimeter of mercury during those portions of the test where data were being recorded and the pressure differential between the test chamber and the exhaust chamber was 0.5 inch of water, the exhaust chamber pressure always being the lower.

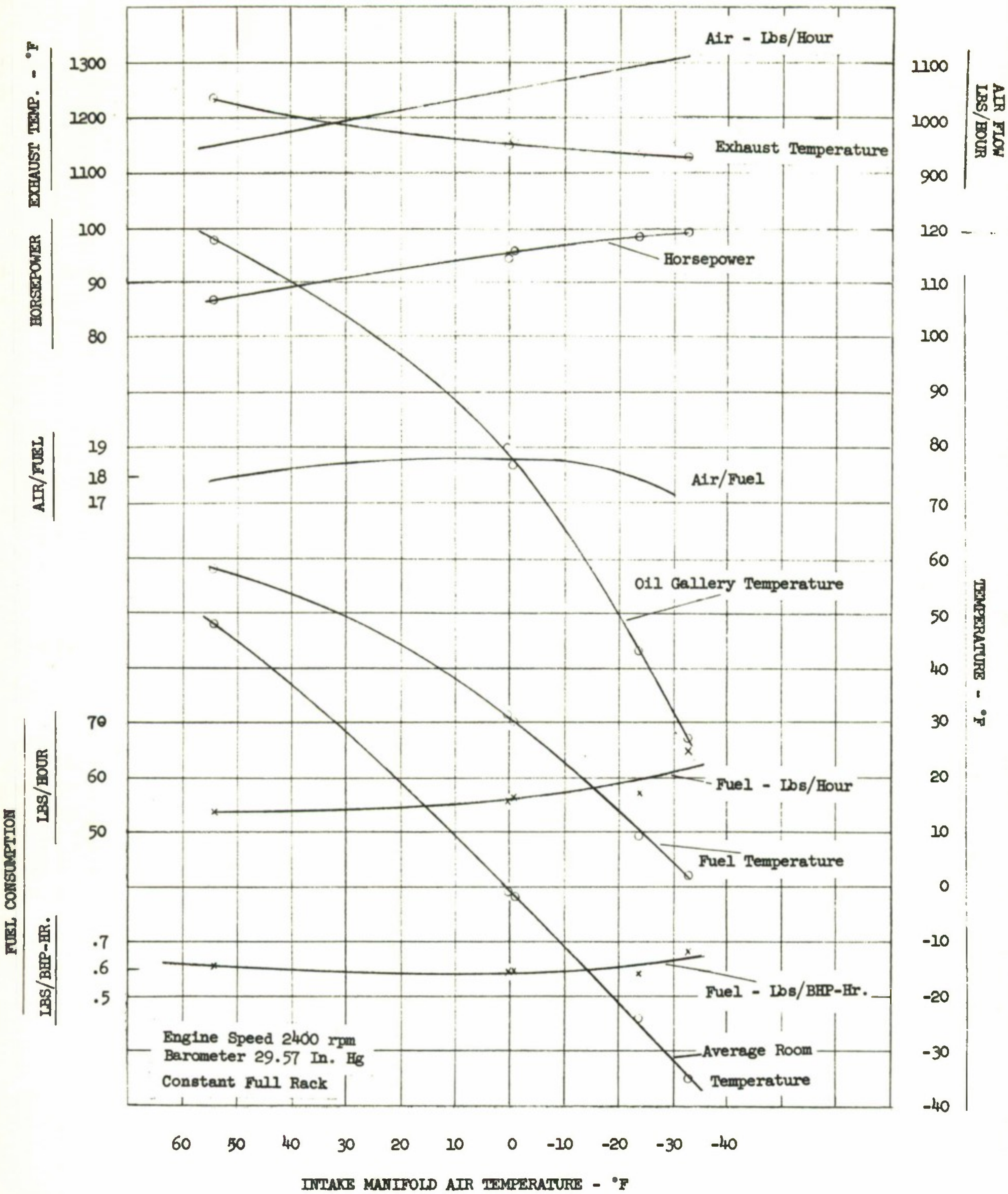


Figure 11: Effect of Environment on Engine Performance and Temperatures.

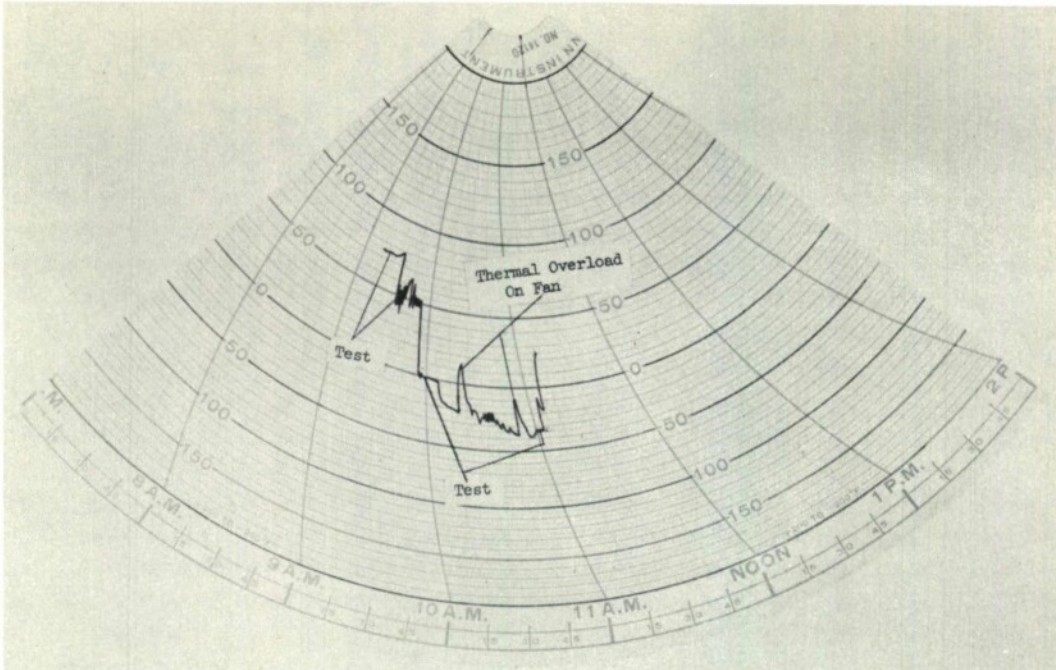


Figure 12: Rate of Temperature Change in the Test Chamber With the Engine Operating.

5.4 Combustion Pressure Diagrams

No unusual difficulty was encountered when measuring combustion pressures as a result of operating the engine in the environmental chamber. Examples of pressure records obtained in different environments are shown on Figure 14. The record obtained at sea level was obtained with injection timed at 32°BTC. When operating at simulated altitudes of 5000 feet and above, burning occurred late in the cycle and produced exhaust temperatures of 1500°F and above. Advancing the injection to 38°BTC caused knock, as may be seen in the top record, but reduced the exhaust temperature.

This brief discussion of engine performance is given only to explain the pressure diagrams. Engine performance is not within the scope of this report and will be discussed in a separate report.

5.5 Contamination of Intake Air

There was no contamination of intake air by the exhaust gases. All air was evacuated from the "exhaust" chamber and all fresh air was admitted to the "test" chamber. The pressure differential between the two chambers was monitored throughout all tests and it was found that the pressure drop from the test chamber to the exhaust chamber was never less than 0.3 nor more than 0.5 inch of water. This pressure differential verifies a continuous air flow from the "test" chamber to the "exhaust" chamber which would preclude any possible contamination of the intake air.

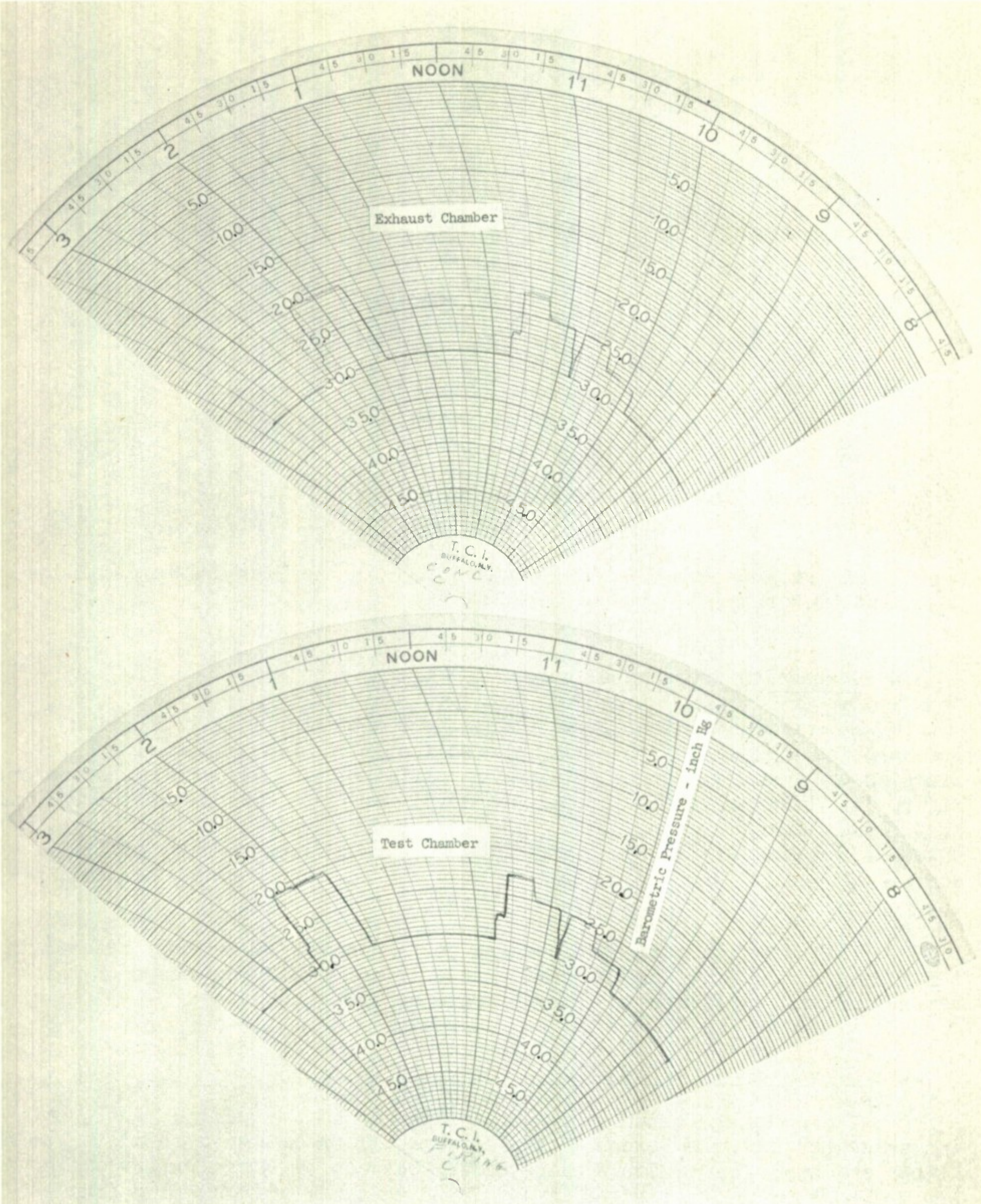
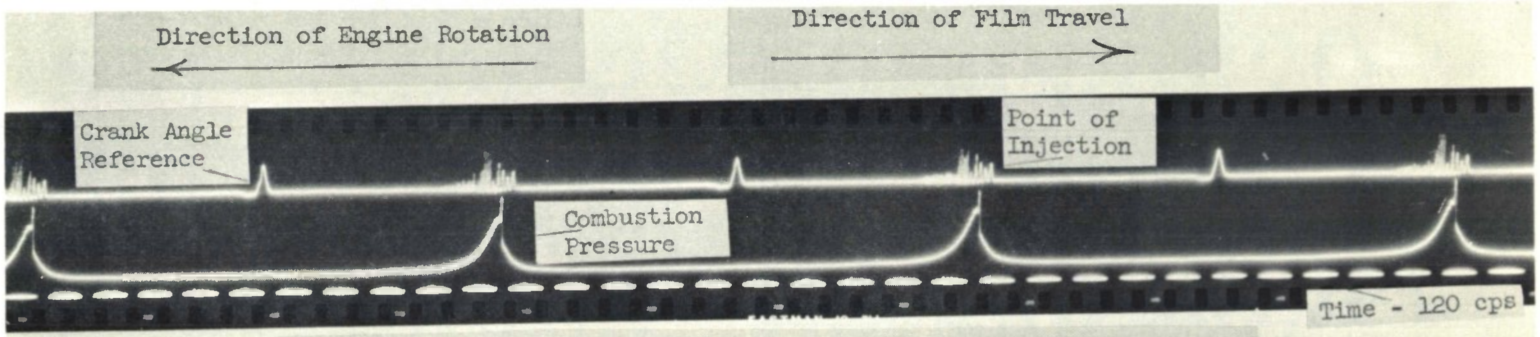
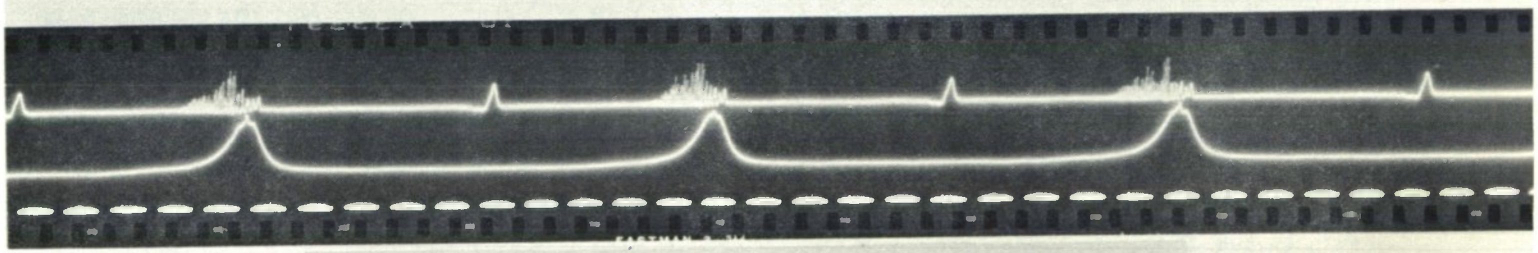


Figure 13: Typical of Rate-of-Pressure Change in the "Test" and "Exhaust" Chambers. It Can Be Seen That the Rate of Response Is the Same for Both Chambers.



1400 Rpm Full Load - 5000 Ft. Altitude - Injection Set at 38°BTC



1400 Rpm Full Load - Sea Level - Injection Set at 32°BTC

FIGURE 14: Examples of Combustion Pressure Diagrams.

6. DISCUSSION

The capacity of the chamber to simulate environments for a 345-cubic-inch engine has been shown in the results. The capacity of the chamber to simulate environments for other engines depends on several variables, such as the volume of air demanded by the engine to be tested, engine heat rejected to the chamber (liquid-cooling versus air-cooling), the rate with which air can be circulated in the chamber, and the heat capacity of the volume of air at the various air pressures as influenced by density. About 1400 cubic feet of air was drawn at sea level through the test chamber and cooled. Of these 1400 cubic feet, about 230 cubic feet was being consumed by the test engine and the remainder was being drawn into the exhaust chamber through the balance tube between the two chambers. It appears, then, that a liquid-cooled engine of perhaps 600-cubic-inch displacement might be operated in the chamber without appreciably raising the minimum obtainable operating temperature.

Physically, the test chamber will hold engines as large as the AVDS-1790 or the AVI-1790 engines together with a dynamometer which will absorb their output. No attempt will be made here to predict the minimum ambient temperature that can be obtained with such an air-cooled engine operating at maximum output.

Minor modifications to the test facility or changes in operating techniques may extend the low-temperature extreme obtainable at both sea level and at simulated altitude. The installation of a larger capacity motor to drive the circulating fans would allow uninterrupted flow of air over the coils at the maximum rate and provide maximum cooling. Changes in operating techniques which would limit the amount of fresh air to the test chamber to that required by the engine and supply the remaining air, which is required to maintain pressure, to the exhaust chamber would reduce the volume of air which must be cooled. Such a technique must insure that exhaust gases are not permitted to contaminate intake air. Some indication of the volume of air supplied to each chamber would be required and the present air-measuring devices (rotameters) on the chamber are virtually useless because their combined capacity is only 225 CFM. The capacity of the rotameter is less than the demand of the 345-cubic-inch engine which was tested.

When large air-cooled engines are to be tested, major modifications to the facility could be employed to extend the minimum operating temperature. Coils could be used to precool the air supplied to the test chamber. Refrigeration for these coils could be supplied by the second compressor system intended to cool the exhaust chamber, or by other methods of providing refrigeration.

A method of obtaining colder intake air, if not of maintaining the chamber at an equally low ambient, would be to duct intake air directly from the coil in the top of the chamber to the engine manifold.

The minimum temperatures reported have all been obtained with a vacuum pump removing exhaust gases from the exhaust chamber. For cold-starting tests or cold-starting and engine warm-up tests at sea level, engine exhaust can be piped through the exhaust chamber to the outside atmosphere; this would allow the engine to be operated without using the vacuum pump. This way, engines of any size can be cold-soaked to -65°F and lower room temperatures can be maintained with the engine running.

The effect of humidity decidedly affects the performance of spark ignition engines, but has a lesser effect on compression-ignition engines (Reference 7). Because this test was conducted using a compression-ignition engine to determine the capacity of the facility to simulate a variety of pressures and temperatures, no effort was made to control the moisture content of the air. For tests where the effect of humidity is important, some control of humidity can be achieved. Desiccating equipment installed in Building 384 can dry air at the rate of 225 cfm. This is about 16% of the 1400 cfm being drawn through the chamber. Minimum humidity obtainable would be that of prevailing ambient humidity less the effect of 16% dry air. By injecting various amounts of steam into the chamber, various moisture contents between ambient and saturation can be obtained.

7. CONCLUSIONS

The environmental chamber can simulate all of the conditions within the basic environmental envelope and about 80% of the extreme environmental envelope for a 350- to 450-cubic-inch, liquid-cooled, compression-ignition engine operating at maximum output.

Modifications to the facility, and changes in operating techniques, will provide about the same environmental conditions for larger and more powerful engines.

The environmental chamber provides a much needed facility for evaluating Ordnance engines with respect to performance, engine and fuel compatibility, and cold-starting and warm-up characteristics.

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REFERENCES

1. "Operation of Materials Under Extreme Conditions of Environment," Army Regulation 705-15 dated 14 August 1957.

2. "Engines, Automotive Type, Internal-Combustion; General Specification," Specification MIL-E-13929 (Ord) dated 23 December 1954.

3. Dodd, A. V. and Thompson, W. F., "Environmental Handbook for the Camp Hale and Pikes Peak Areas, Colorado," Quartermaster Research and Engineering Center, Technical Report No. 79 dated January 1958.

4. Cline, H. T., "High Altitude Vapor Lock Test of Trucks, Cargo, 3/4 Ton, 4x4, M37 at Death Valley, California," Automotive Engineering Laboratory, Development and Proof Services, Aberdeen Proving Ground, Maryland, Report No. 53-100-K, Dated 23 September 1953.

5. Johnk, R. E., "High Altitude Vapor Lock Test of Trucks, Cargo, 2½ Ton, 6x6, M35 at Death Valley, California." Automotive Engineering Laboratory, Development and Proof Services, Aberdeen Proving Ground, Maryland, Report No. 53-100-J, dated 24 September 1953.

6. dePercin, F., Miller, R. C., Falkowski, S. "Handibook of Big Delta (Fort Greely), Alaska Environment." Quartermaster Research and Engineering Center, Technical Report EP-5, dated April 1955.

7. Ordnance Proof Manual, Volume II, "Automotive Testing," Section OPM 60-303, Aberdeen Proving Ground, Md. dated 10 April 1958.

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